Predicting Contaminant Removal Effectiveness of Three Air Distribution Systems by CFD Modeling

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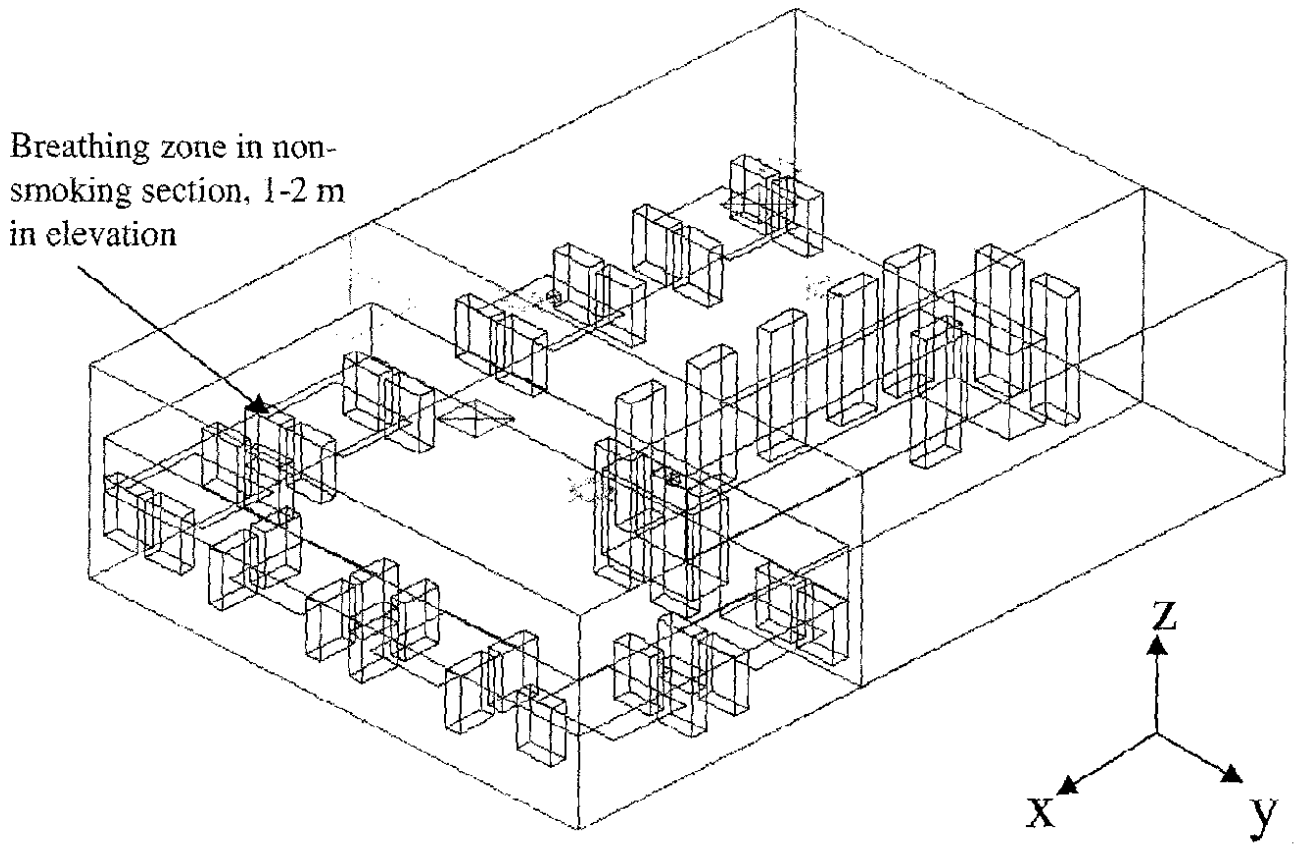
ABSTRACT:

This study compares the contaminant removal effectiveness (CRE) of three air distribution systems for a bar/restaurant setting by use of computational fluid dynamics (CFD) modeling. The air supply distribution and exhaust arrangement were modeled for a **mixed air system**, a **directional air flow system** (where air moves in a unidirectional flow pattern across the space, from the high pressure supply area to the low pressure exhaust area), and a **displacement ventilation system** (where supply air is delivered at low velocity close to floor, allowing thermal plumes to be created). The CRE of each space was determined for both particulate and carbon monoxide dispersions under two different ventilation rates. A commercial CFD software package was used to model a hypothetical restaurant with bar in a steady state condition with the inclusion of objects, such as a bar and multiple tables, heat sources such as people standing and seated, pollutant sources, multiple four way supply air diffusers, and an exhaust air grille. The hospitality spaces' smoking and non-smoking zones had no physical separation. The results demonstrated that directional airflow systems reduce non-smokers exposure to contaminants better than mixed air systems, and displacement ventilation systems reduce non-smokers exposure better than both directional airflow and mixed air systems.

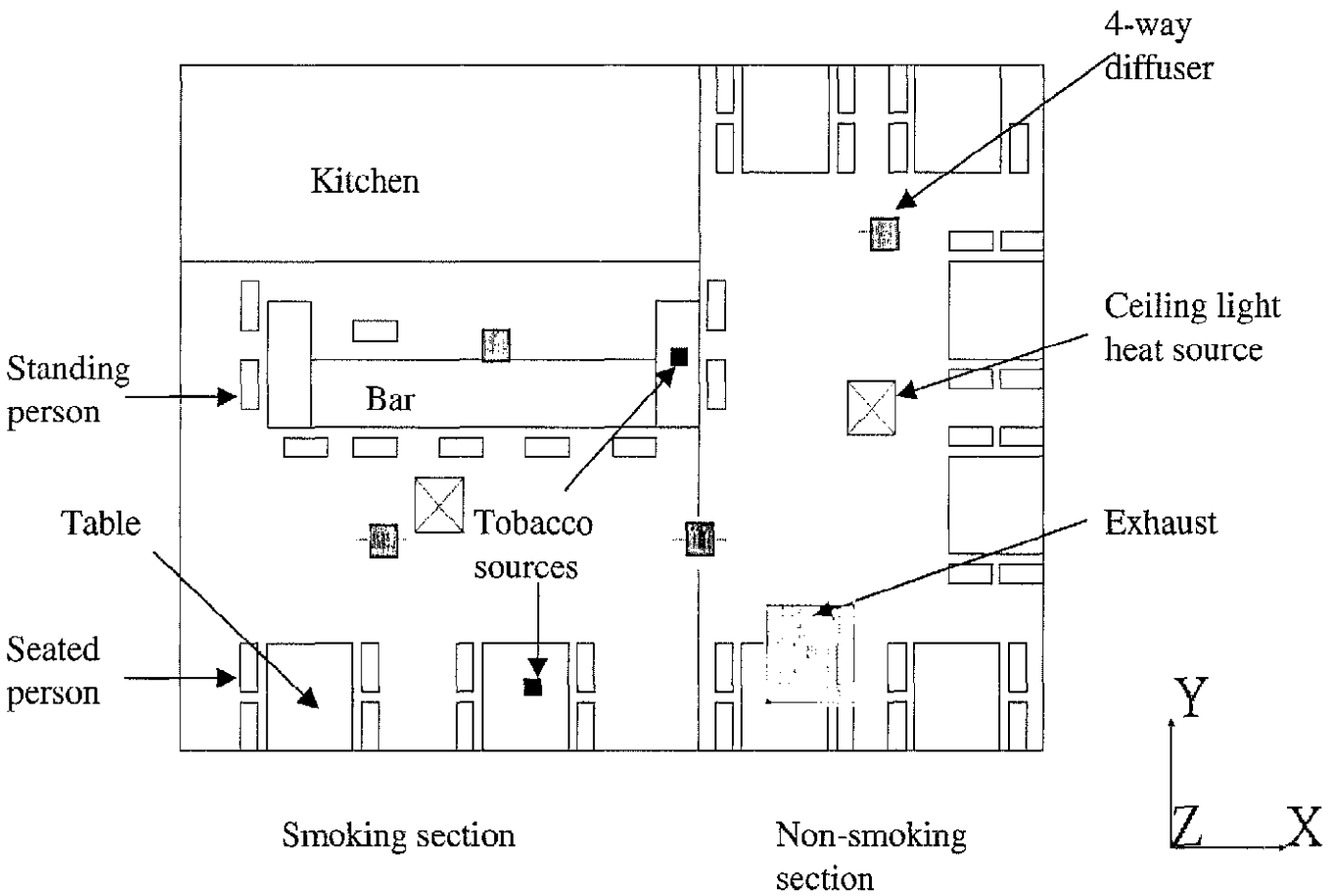
Study Design

- Hospitality space with airflow obstructions, heat and tobacco sources
- Computational fluid dynamics (CFD) modeling in a steady state condition
- Room air velocities, temperatures, particulate and CO concentrations solved for each HVAC arrangement:
  - Mixed air
  - Directional
  - Displacement ventilation
- Ventilation rates
  - ASHRAE 62-1989 ventilation rate 472 L/s (1000 cfm outdoor air)
  - ½ ASHRAE 62-1989 ventilation rate 236 L/s (500 cfm outdoor air)
- Contaminant removal effectiveness (**CRE**) based on particulate or CO concentrations
  - $CRE = (C_{exhaust} - C_{supply}) / (C_{region} - C_{supply})$

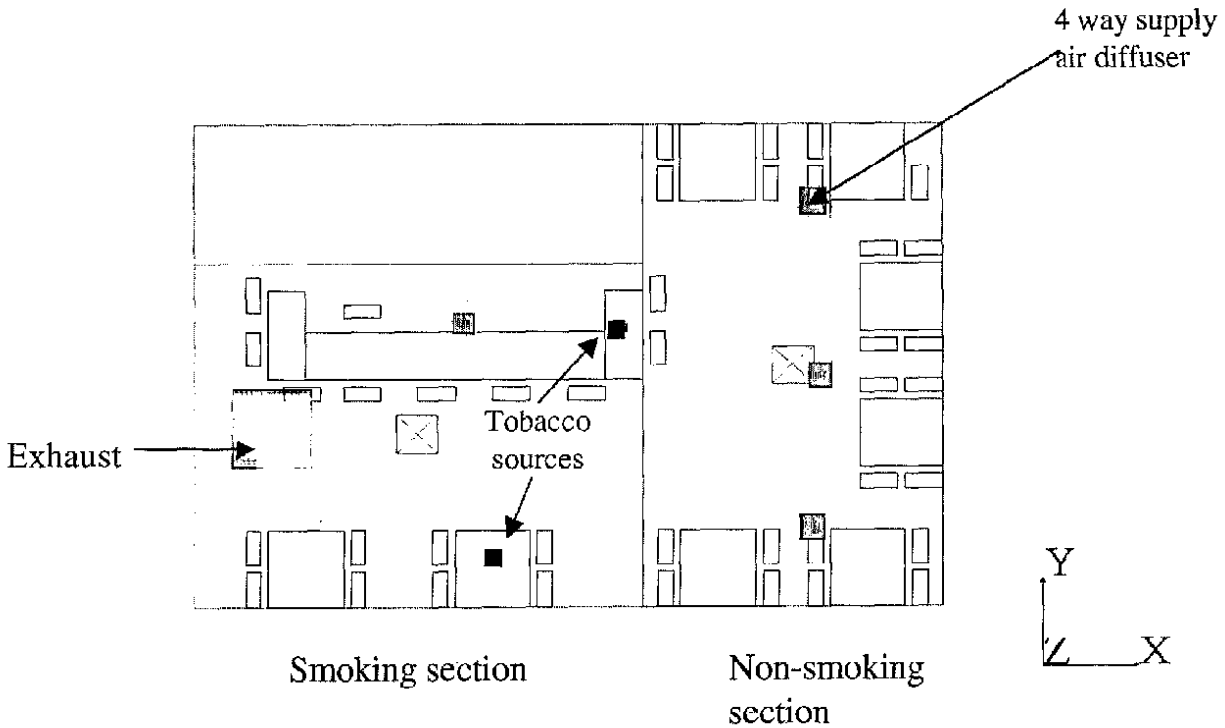
Perspective view of modeled space



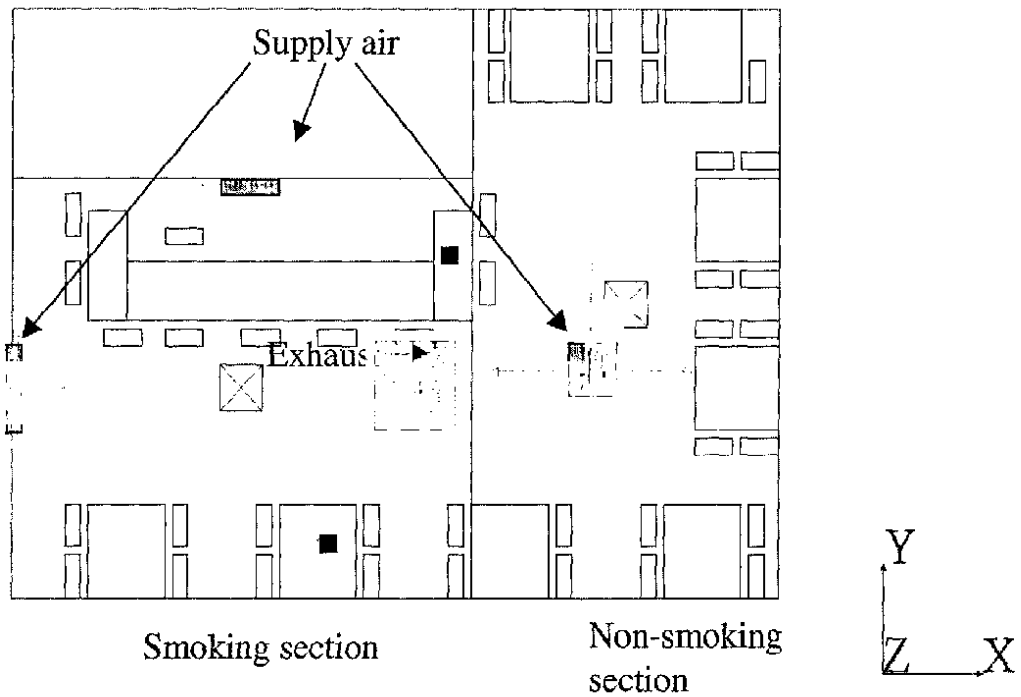
Mixed Airflow : Room geometry



Directional Airflow : Room geometry

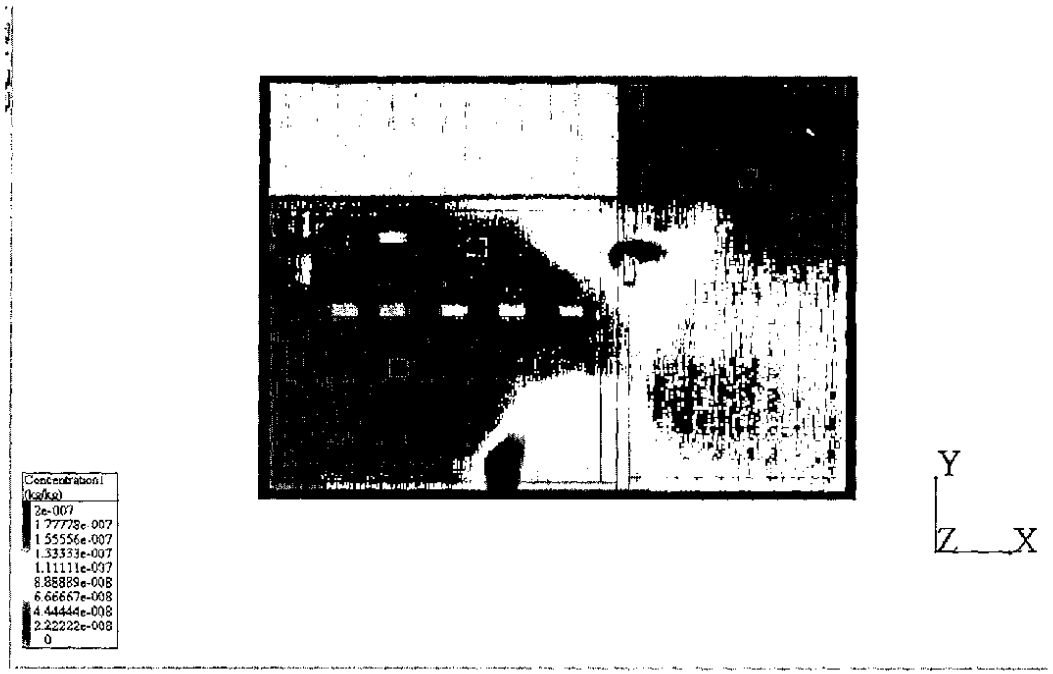


Displacement Ventilation : Room geometry

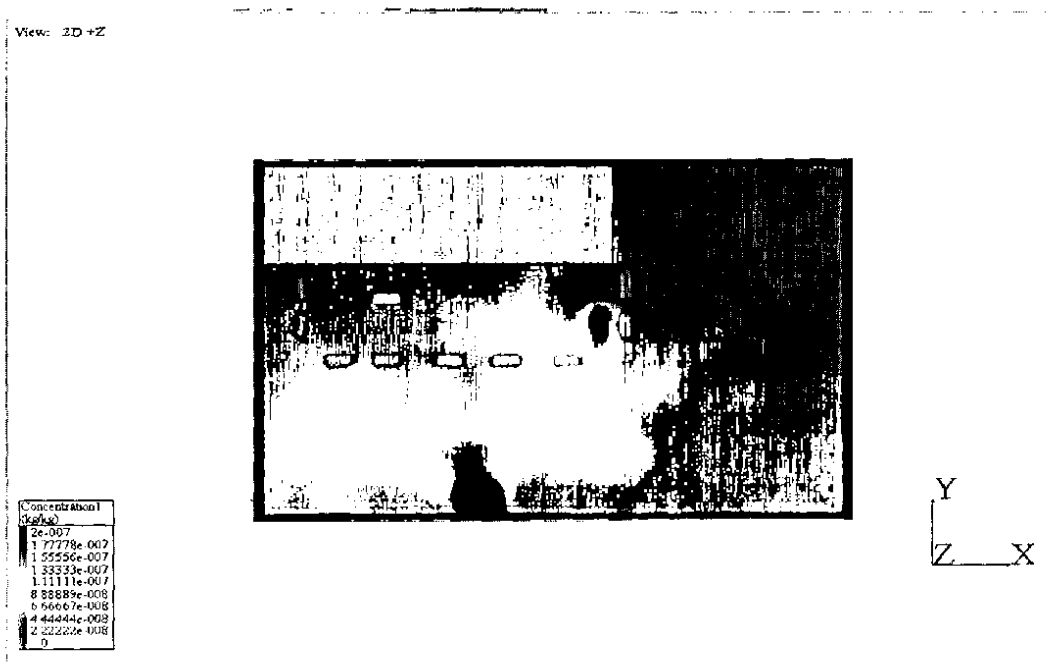


RESULTS:

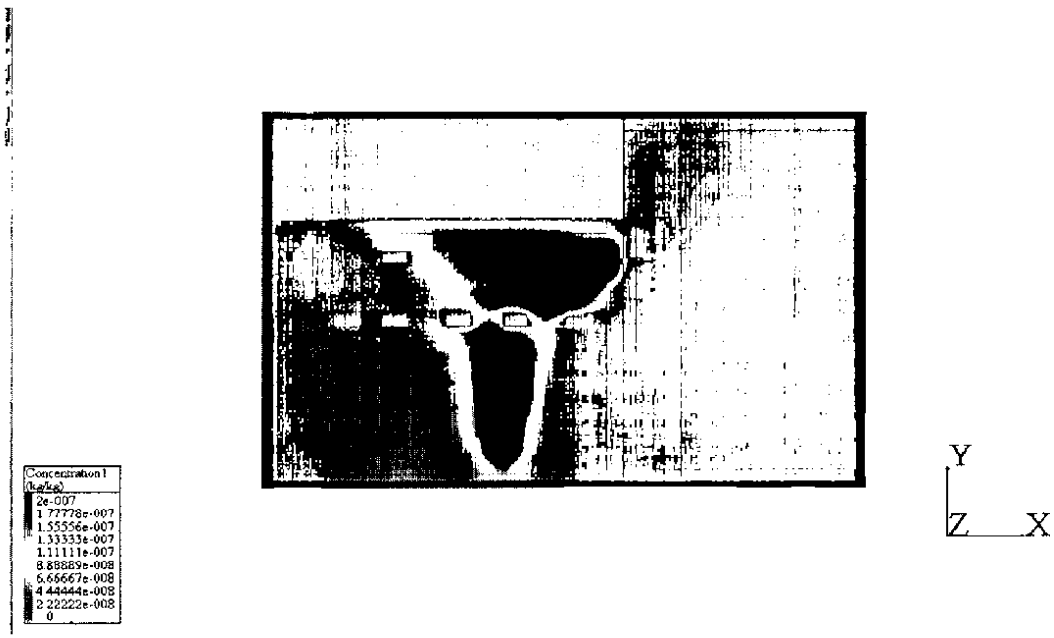
Mixed Airflow : Particle concentration 1.7 m above floor @ 472 L/s



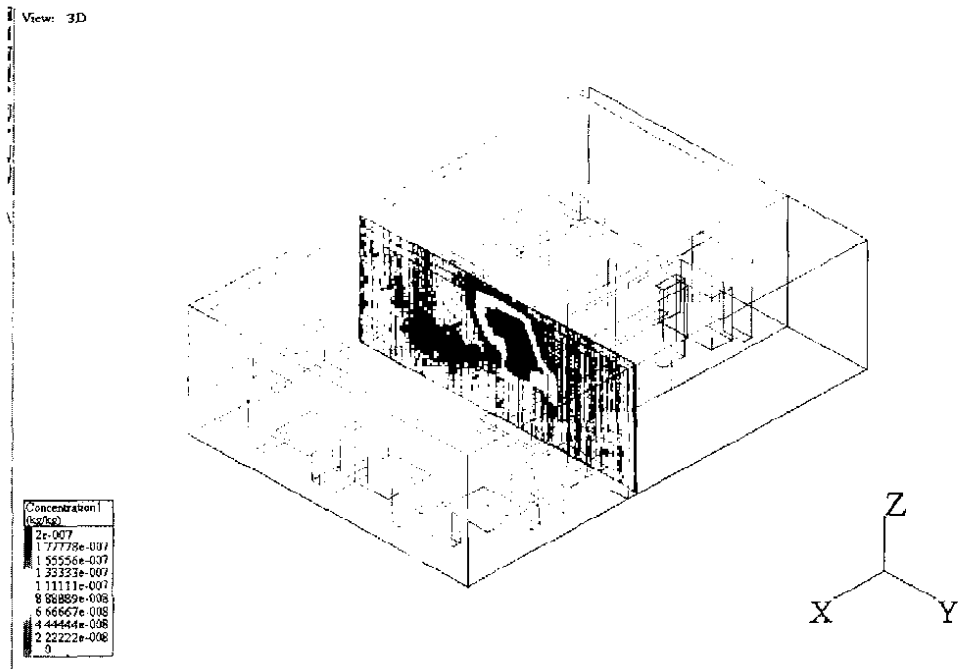
Directional Airflow : Particle concentration 1.7 m above floor @ 472 L/s



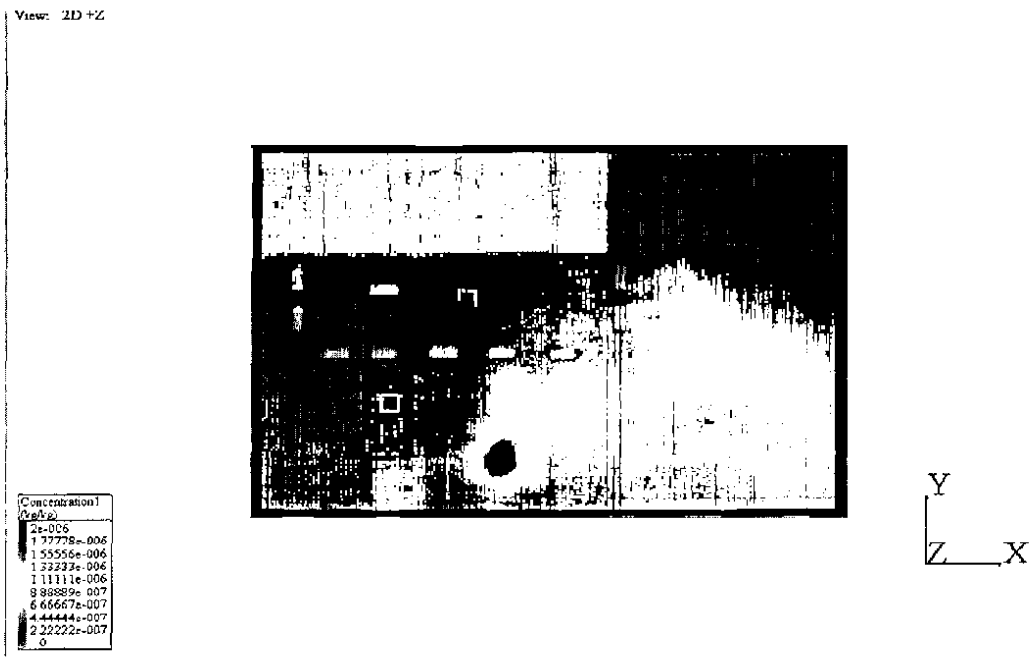
Displacement Ventilation : Particle concentration 1.7 m above floor @ 472 L/s



Displacement Ventilation : 3D view cut through one smoke source showing particulate plume from one tobacco source

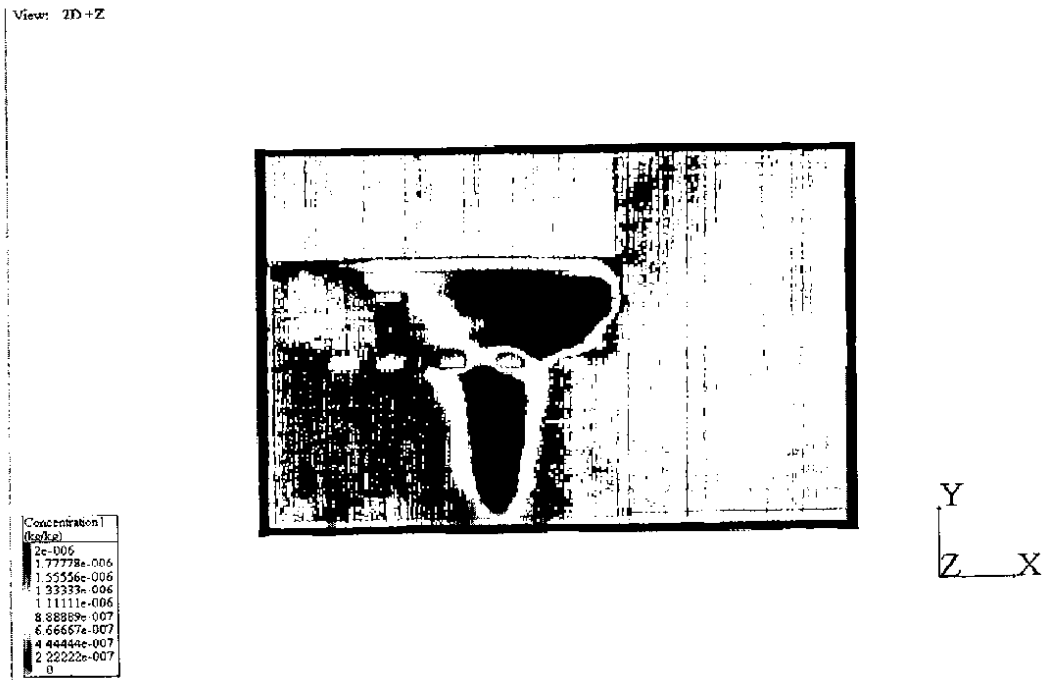


Mixed Airflow : CO concentration 1.7 m above floor @ 472 L/s



Directional Airflow : CO concentration 1.7 m above floor @ 472 L/s

Displacement Ventilation : CO concentration 1.7 m above floor @ 472 L/s

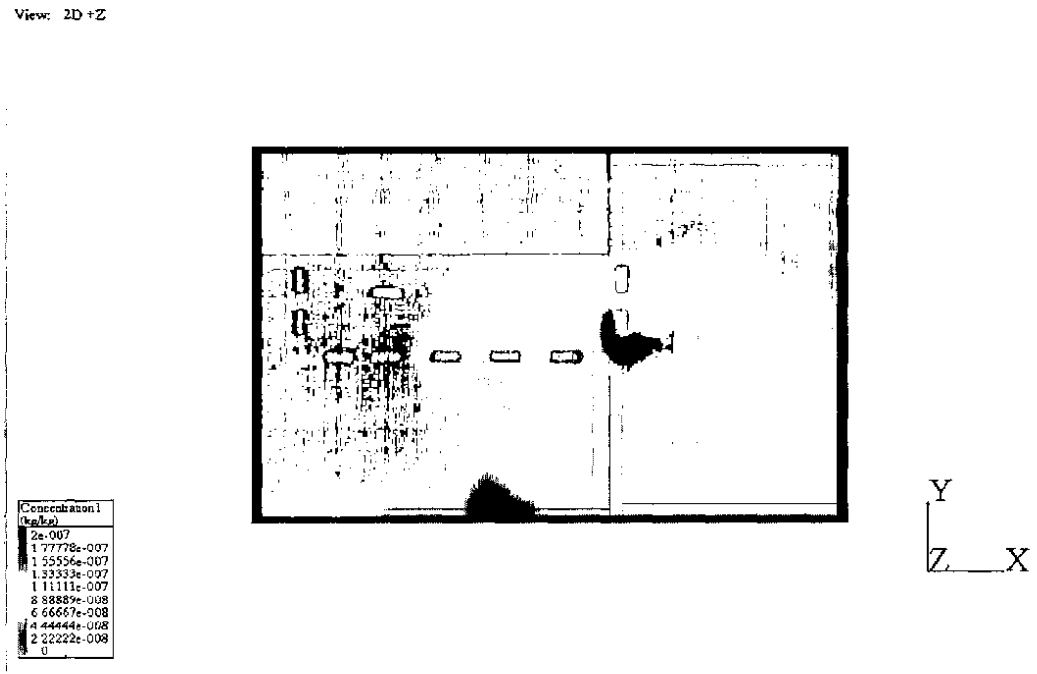


Ventilation Rate of 472 L/s

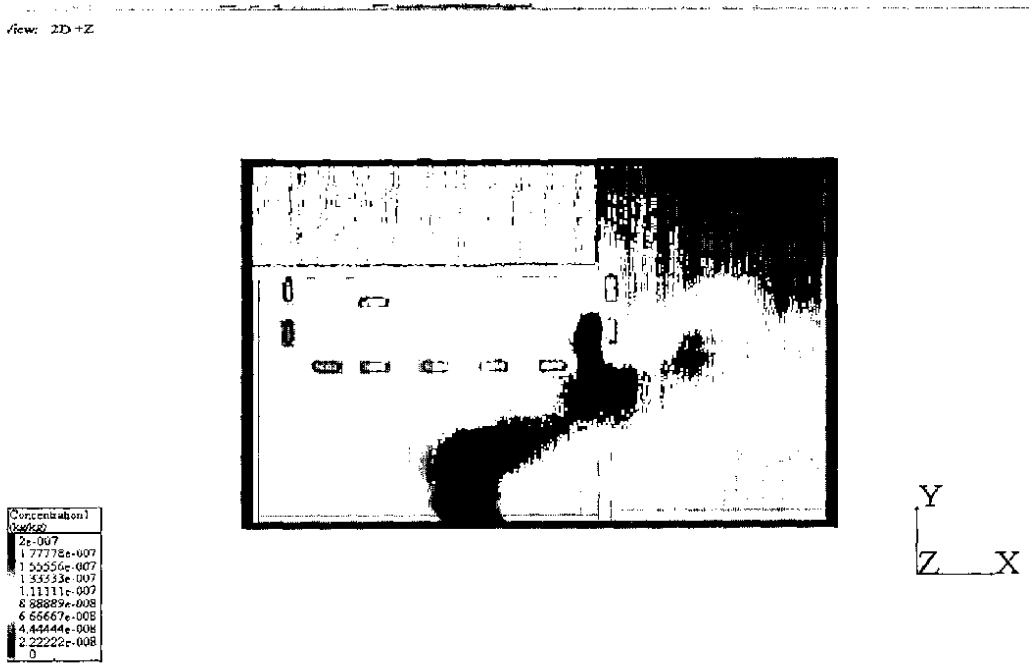
Parameters (unit of measure)	Mixed Air	Directional Airflow	Displacement Ventilation
Total supply airflow, L/s	472	472	472
Particle concentration exhaust, $\mu g/m^3$	**70**	**70**	**70**
Particle concentration non-smoking region, $\mu g/m^3$	**63**	**26**	**4**
Particulate contaminant removal effectiveness (CRE)	**1.1**	**2.7**	**17.5**
CO concentration exhaust, $\mu g/m^3$ (ppm)	**631 (0.6)**	**629 (0.6)**	**631 (0.6)**
CO concentration non-smoking region, $\mu g/m^3$ (ppm)	**624 (0.6)**	**243 (0.2)**	**40 (0.0)**
CO contaminant removal effectiveness (CRE)	**1.0**	**2.6**	**15.8**

Note: Bold indicates calculated results from input data.

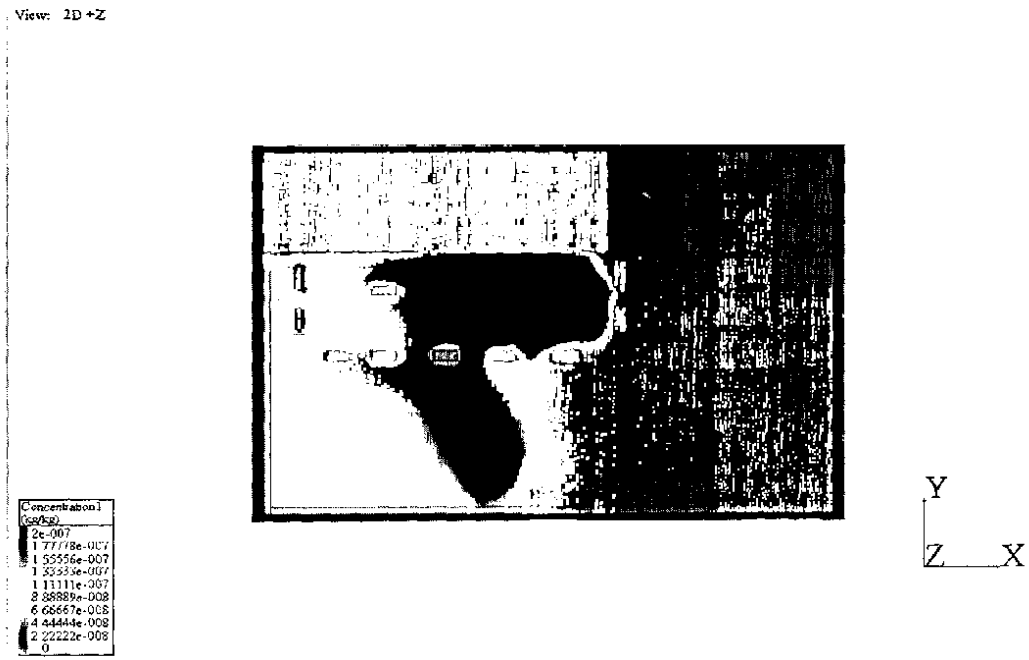
Mixed Airflow : Particle concentration 1.7 m above floor @ 236 L/s



Directional Airflow : Particle concentration 1.7 m above floor @ 236 L/s



Displacement Ventilation : Particle concentration 1.7 m above floor @236 L/s



Ventilation Rate of 236 L/s

Parameters (unit of measure)	Mixed Air	Directional Airflow	Displacement Ventilation
Total supply airflow, L/s	236	236	236
Particle concentration exhaust, $\mu g/m^3$	**140**	**141**	**140**
Particle concentration non-smoking region, $\mu g/m^3$	**120**	**98**	**19**
Particulate contaminant removal effectiveness (CRE)	**1.2**	**1.4**	**7.4**
CO concentration exhaust, $\mu g/m^3$ (ppm)	**1274 (1.1)**	**1268 (1.1)**	**1269 (1.1)**
CO concentration non-smoking region, $\mu g/m^3$ (ppm)	**1081 (0.9)**	**878 (0.8)**	**157 (0.1)**
CO contaminant removal effectiveness (CRE)	**1.2**	**1.4**	**8.1**

Note: Bold indicates calculated results from input data.

Conclusions

- The ranking in order of highest CRE is:
  - Displacement ventilation (7.4-17.5)
  - Directional airflow (1.4-2.7)
  - Mixed airflow (1.0-1.2)
- Particulate and CO distribution from tobacco sources are vastly different in diffusivity but both move with the prevalent air current within a space
- CFD modeling can be a useful HVAC/IAQ design tool